Stroke Telemedicine

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Stroke telemedicine is a consultative modality that facilitates care of patients with acute stroke at underserviced hospitals by specialists at stroke centers. The design and implementation of a hub-and-spoke telestroke network are complex. This review describes the technology that makes stroke telemedicine possible, the members that should be included in a telestroke team, the hub-and-spoke characteristics of a telestroke network, and the format of a typical consultation. Common obstacles to the practice of telestroke medicine are explored, such as medicolegal, economic, and market issues. An example of a state-based telestroke network is thoroughly described, and established international telestroke networks are presented and compared. The opportunities for future advances in telestroke practice, research, and education are considered.

***Mayo Clin Proc.* 2009;84(1):53-64**

ADHS = Arizona Department of Health Services; AV = audiovisual; CT = computed tomography; IRB = institutional review board; MeSH = medical subject heading; NIH = National Institutes of Health; PSC = primary stroke center; STARR = Stroke Telemedicine for Arizona Rural Residents; STRokE DOC = Stroke Team Remote Evaluation Using a Digital Observation Camera; TIME = The Initial Mayo Clinic Experience; tPA = tissue plasminogen activator

Studies have described variability in the depth of stroke care provided at hospitals in the United States and abroad.[1,2] Although primary stroke centers (PSCs) are equipped with the resources and personnel to provide patients with acute stroke with a timely, adequate assessment and emergency stroke treatments, they represent only a minority of all hospitals. Unfortunately, this level of expertise may be unavailable at some urban and most rural centers that do not specialize in stroke. This gap in availability of emergency stroke care can be attributed to a low number of certified PSCs, insufficient availability of stroke specialists, and long distances between remotely located patients and centrally located stroke specialists.[3,4] Accordingly, therapies for acute stroke, such as tissue plasminogen activator (tPA), are underused by hospitals that cannot provide patients with timely access to stroke expertise. To overcome this gap in availability of and access to stroke specialists and to address the underuse of therapies for acute stroke, telemedicine techniques that are adapted to the emergency evaluation of acute stroke can be used.[5] According to the American Telemedicine Association, *telemedicine* is the exchange of medical information from one site to another using electronic communication, such as telephone, Internet, or videoconference.[6] Telemedicine practices allow for a specialist consultation, direct patient consultation, patient monitoring, and medical education. The application of telemedicine for care of acute strokes, often called *telestroke*, was a natural progression from general telemedicine because of a shortage of stroke neurologists and recent advances in technology.[2]

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Telecommunications, which started with the telephone and advanced to audiovisual (AV) communication, has changed the face of medicine not only in remote areas but also in urban areas with a shortage of subspecialists. A surge in the use of telestroke across the United States, Canada, and Europe occurred in the late 1990s and early 2000s, resulting in the development of 20 new telestroke networks. In this review, *telestroke* refers to live, AV telecommunication applied to care of acute stroke. The implementation of telemedicine for stroke is a vital piece to the puzzle of creating universal access to emergency care for all patients with stroke, regardless of geographic location or hospital resources.[7]

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This study was funded by an Arizona Department of Health Services research grant (HI754123), a Mayo Clinic research grant (90256993), the STRokE DOC Arizona—The Initial Mayo Experience (TIME) trial (clinicaltrials.gov identifier: NCT00623350), and the Stroke Telemedicine for Arizona Rural Residents (STARR) Registry.

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TABLE 1. **Comparison of Telemedicine Systems**

Factor	BF Technologies[a] (San Diego, CA)	Polycom[b] (Pleasanton, CA)	Tandberg[c] (New York, NY)	InTouch Health[d] (Santa Barbara, CA)	Remote Evaluation of Acute Ischemic Stroke Call (REACH)[e] (Augusta, GA)	Specialists On Call[f] (Westlake Village, CA)
Product offering	AccessVideo Telemedicine	VSX/HDX Practitioner Cart System	Tandberg Intern MXP	RP-7 Remote Presence System (integrates robotic platform audiovisual)	Web-based tools that integrate audiovisual communication into clinical practice	Third-party provision of physicians on call 24 h/d, 7 d/wk via video-conference software
Hardware provided	Yes	Yes	Yes	Yes	No	No
Software	Yes	Yes	Yes	Yes	No	No
Web-based	No	No	No	No	Yes	Yes
Annual cost (US $)	~24,000	~25,000	~25,000	Varies	On the basis of monthly stroke volume	On the basis of monthly stroke volume
Maintenance fee	Yes	Yes	Yes	Yes	No	No
Technology support 24 h/d, 7 d/wk	Telephone	Telephone and online	Telephone and online	Continuously monitored	Telephone and online	Telephone and online request
Radiology transmission	Yes	Yes	Yes	Yes	No	No

[a] Web site: http://www.bf-technologies.com/.
[b] Web site: http://www.polycom.com/usa/en/solutions/industry_solutions/healthcare/tele_medicine.html/.
[c] Web site: http://www.tandberg,com/ind_focus/healthcare/hc/_solutions.jsp.
[d] Web site: http://www.intouchhealth.com/products_rp7robot.html.
[e] Web site: http://www.reachcall.com/company.html.
[f] Web site: http://.brainsavingtech.com.

METHODS

A team of clinicians (B.M.D., M.L.M.) and a medical librarian (K.E.W.) independently developed search strategies, reviewed the medical literature, screened titles and abstracts, identified potentially useful articles, extracted the relevant information, and assembled the review. The literature search was conducted in the following Ovid databases: MEDLINE (1950 to 2008), EMBASE (1988 to 2008), Healthstar (1966 to 2008), and CINAHL (Cumulative Index to Nursing and Allied Health Literature, 1982 to 2008). In July 2008, the search was repeated in MEDLINE to identify any additional published articles. The same combination of medical subject heading (MeSH) terms, textwords, and keywords was used in all databases. The MeSH terms *cerebrovascular accident, cerebral infarction, brain ischemia, ischemic attack, transient, cerebrovascular disorders,* and *tissue plasminogen activator* were all exploded and combined using the Boolean operator "OR." Textwords *tPA* and *stroke* were added to create one set. Another set was created using the exploded MeSH terms *telemedicine, telecommunications,* and *remote consultation* and the textwords *telemedicine* or *telemedical*. A collection of journals in the area of telemedicine was also included in the last set with the "OR" operator. The 2 sets (set of stroke results and set of telemedicine results) were combined using the Boolean operator "AND" and limited to the English language. Review articles on telemedicine in general were also consulted. The bibliographic database search was supplemented by hand searching for published abstracts, consultations with investigators and practitioners in the field, and review of conference proceedings. Duplicate publications were removed.

TELESTROKE TECHNOLOGY AND SERVICES

One early step in designing a telestroke network is selecting an operating system. Information technology support is essential because the chosen system should be applicable within any new or existing telestroke network. A growing interest in telestroke has led to the development of numerous equipment options for the stroke telemedicine team. Popular equipment for telestroke includes a hardware and software package, such as the systems provided by Polycom (Pleasanton, CA), Tandberg (New York, NY), BF Technologies (San Diego, CA), and InTouch Health (Santa Barbara, CA). Alternatively, REACH Call (Augusta, GA) and Specialists On Call (Westlake Village, CA) are Web-based online services for videoconferencing between a patient and a stroke specialist.

Table 1 presents a comparison of these telemedicine systems. In the current era of technology, an ideal telestroke system should involve a 2-way AV connection for assessment and diagnosis of patients with stroke. Telemedicine systems enable online, real-time communication using a digital camera and software that are controlled by the stroke specialist. The interrater reliability of a neurological examination and a National Institutes of Health (NIH) Stroke Scale score obtained by AV teleconferencing equipment was found to be excellent. Multiple studies concluded that remote examinations of patients with acute stroke with these systems are feasible and reliable.[8-10] Most equipment choices feature a high-resolution digital camera, microphone, speakers, server for scan storage, and a monitor for the patient to view the telestroke practitioner. Maintenance needs are typically minor.

Computed tomography (CT) transmission via a picture archiving and communication system is relatively easy to learn and implement into telestroke practice. Privacy and security of the system can be maintained by secure socket layer conditional access, data encryption, intruder alerts, and access logging and reporting. These security features ensure Health Information Portability and Accountability Act adherence for virtual telestroke consultations. Most operating systems incorporate a remote pan-tilt-zoom interface to give a remote user full control over the transmitted image. An added feature of recording capability allows the consultant to record and store the AV consultation.

HUB-AND-SPOKE MODEL CHARACTERISTICS

Fisher[11] proposed a hub-and-spoke model of telemedicine-delivered stroke care designed to enhance the administration of acute stroke therapies. Evidence-based care[5] from the hub, which should ideally be a Joint Commission–certified PSC,[12] is transmitted to the spokes. Hubs are generally located in urban areas, and spokes are usually located in rural regions or in urban hospitals that are not stroke centers. The optimal telestroke spoke hospital has a sufficient volume of patients with acute stroke but does not have available neurologists on call for emergencies. In addition, the emergency department staff should be receptive to collaborating on a telestroke program, should have access to CT 24 hours per day 7 days per week, and should be supported by hospital administration. Collaboration between hub and spoke hospitals with these characteristics lays the foundation for maturation of stroke practice skills and credentials.

Ideally, spoke hospitals should track the same stroke performance measures as hub PSCs track. An experienced spoke hospital could attain PSC certification via established telestroke practice. The spoke center should use stroke quality measures from patient admission to discharge. The spoke center would not be required to admit all patients with stroke to attain PSC status; rather, transfer agreements with other institutions could be established for stroke patients with advanced care needs. As the guidelines for comprehensive stroke centers[13] are further refined for implementation and practice, the spoke hospital's acquisition of PSC status and the hub hospital's acquisition of comprehensive stroke center status would be inherent in the hub-spoke relationship.

TELESTROKE TEAM MEMBERSHIP

The telestroke team should consist of a broad range of clinical, administrative, and research members at both the hub and spoke[14] to fulfill all aspects of the telestroke dynamic. Table 2 lists the proposed members of a telestroke team. Neurologists, emergency physicians, nurses, and radiologists should collaborate on the provision of remote care for patients with acute stroke. In general, telestroke practitioners are board-certified vascular neurologists; however, no formal requirements for the practice of telestroke currently exist. In reality, any trained practitioner in the field of stroke could learn the requisite skills of telestroke assessment because these skills are not difficult to acquire.[15] Stroke neurologists, often aided by a remote bedside nurse, can quickly and reliably obtain valid NIH Stroke Scale scores by a high-speed AV telemedicine link.[8-10] Potentially efficient models of telestroke systems might use vascular neurology fellowship–trained nurse practitioners, physician assistants, or neurology residents and fellows to perform preliminary triage, screening, and neurologic assessments. This preliminary work could then be followed by a reassessment or review by a supervising vascular neurologist, depending on pertinent state laws. Having emergency medicine physician stroke leaders participate at hub-and-spoke centers is a model that appears to be associated with program success.[16]

TABLE 2. **Team Members of a Stroke Telemedicine Network**

Hub hospital	Spoke hospital
Director (vascular neurologist)	Director (emergency physician)
Codirector (emergency physician)	Site coordinator
Program coordinator/project manager	Emergency physician
Neurologist	Information technologist
Information technologist	Radiology technologist
Nurse practitioner or physician assistant	Credentialing and privileging assistant
Lawyer	Lawyer
Administrative assistant	Radiologist
Financial analyst	Emergency nurse
Operations administrator	
Research coordinator	

To gain the endorsement of spoke hospitals, a successful collaboration between neurology and emergency medicine practitioners is essential. Collaboration between emergency medicine and neurology practitioners is probably the most important element of a successful telestroke program. By definition, spoke hospitals are underserviced or undersupported by neurologists, which creates the need for telestroke. For several reasons, many emergency physicians are hesitant to accept the sole responsibility for administering intravenous thrombolysis for acute ischemic stroke. As a result, these emergency physicians are not using the available acute stroke treatments, such as tPA.[17,18] In contrast, nearly 90% of rural emergency departments would be receptive to joining a telestroke network and

TABLE 3. **Suggested Target Intervals (From Emergency Department Arrival to Activity) for a Telestroke Consultation**[a]

Activity	Time (min)
Emergency department arrival	0
Triage nurse assessment	5
Emergency physician assessment	10
Laboratory tests and CT of head ordered	15
Laboratory tests and CT of head conducted	25
Telestroke hotline activated by spoke hospital	30
Preliminary telephone communication between hub and spoke hospitals	35
2-Way audiovisual telestroke consultation commences	40
Teleradiology review of head CT	45
Diagnosis of stroke established and eligibility for short-term treatment determined	55
Treatments recommended and administered	60
Admission or transfer arranged, marking end of telestroke consultation	65
Consultation note dictated by hub hospital neurologist	75
Consultation note transcribed and transmitted to spoke hospital	120

[a] CT = computed tomography.

treating patients with acute stroke with thrombolysis if a vascular neurologist could provide a telemedicine consultation.[19]

Telestroke networks could benefit from a full-time program manager to bridge the clinical and administrative aspects of a network. Spoke radiology technologists serve the critical role of ensuring that neuroimaging is transferred successfully to allow hub teleradiologic interpretation. Information technologists are invaluable to the initial development, maintenance, and expansion of the network's telecommunication requirements. Education specialists may help to apply continuing medical education credits to stroke tele-education opportunities. Research coordinators are involved in any research effort ranging from the maintenance of a simple prospective registry to a sophisticated randomized controlled trial of telemedicine-delivered experimental therapy. Institutional review board (IRB) specialists may be necessary at institutions less familiar with the unique aspects of conducting teleresearch. Finance specialists may help explore all of the currently available reimbursement opportunities for the hub provider and spoke recipient of the teleconsultations. Business and administration leaders, guided by legal counsel that is familiar with telemedicine law, assist with the development of regulatory documents and contracts between the respective institutions. Credentialing, privileging, and licensing experts assist the hub teleconsultants in establishing the appropriate authorization to perform remote stroke teleconsultations. Depending on the setting of the telestroke practice, a telestroke hotline service should be implemented with the requisite support personnel. Risk management and quality should be involved at both the hub and spoke. Teamwork between personnel at hubs and spokes is essential to a successful telestroke practice.

THE MODEL TELESTROKE CONSULTATION

Acute stroke is a time-sensitive condition that requires multidisciplinary coordination; therefore, the American Stroke Association created the stroke chain of survival to improve clinical outcomes.[5] Although this sequence of events progresses smoothly for patients who have direct access to expert stroke care, this model becomes interrupted for patients who are remotely located and lack this immediate access. When the chain of survival breaks, patients who may have benefited from specific short-term therapies ultimately suffer. The overall goal of a telestroke consultation is to restore the stroke chain of survival and to maximize patient recovery by delivering a timely assessment, making an accurate diagnosis, determining eligibility for short-term therapy, and delivering the chosen treatment. Beginning with a patient's early recognition of stroke symptoms and culminating in a successful telestroke consultation, each step along the way is crucial to the final outcome. Table 3 depicts possible steps and target times for the telestroke chain of survival. The spoke emergency physician performs a quick assessment, recognizes an acute stroke syndrome, and activates the telestroke hotline at the hub site (Figures 1 and 2). Developing an algorithm for the step-by-step conduct of a telestroke consultation is important to developing a telestroke standard of care. In ideal practice, the spoke and hub centers should use the same stroke alert algorithm to create continuity of care throughout an acute stroke evaluation.

ILLUSTRATIVE TELESTROKE CASE

A 75-year-old female resident of a rural community identified the sudden onset of left facial droop, slurred speech, and weakness and numbness of the left arm and leg at 3:30 PM. She presented to the local emergency department of the spoke hospital at 4:21 PM, at which time the emergency department physician examined her and initiated a stroke alert. Blood samples were drawn, CT was completed, and the spoke center activated the telestroke hub hotline. The hub center's on-call stroke neurologist responded. After the patient had undergone CT, the telestroke camera system was placed in front of the patient and the consultation began at 5:08 PM. The patient and her family interacted with the stroke neurologist via the camera system, answered questions, and engaged in the consultation. The spoke emergency department nurse assisted the stroke neurologist with the examination and the laboratory results. The stroke neurologist zoomed in on the cardiac monitor to observe the patient's electrocardiographic results, heart rate, blood pressure, respiratory rate, and oxygen saturations. During the AV telemedicine examination, the stroke neurologist simultaneously accessed the CT by a Digital Imaging and Communications in Medicine system. Through examination via the AV camera system, the NIH Stroke Scale score was determined to be 6. After the clinical, laboratory, and CT examinations were complete, the neurologist requested the presence of the emergency physician and the daughter at the bedside to discuss the plan for care. At 5:53 PM the stroke neurologist reviewed the observations and recommended the administration of tPA. The spoke emergency department initiated tPA at 6:09 PM. The hub stroke neurologist dictated a consultation and faxed it to the spoke center emergency department.

FIGURE 1. A spoke hospital emergency physician at a mock patient's bedside is assisting the hub hospital stroke neurologist with the examination.

THE MEDICOLEGAL ISSUES

The practice of telemedicine in the United States is under the control of the individual states, requires state licensure, and is limited by state geographic boundaries. Internet-based, site-independent approaches to acute stroke care allow a physician-patient interaction to take place when the 2 parties are in different geographic locations anywhere in the world. The jurisdiction restrictions placed on telemedicine practice constrain the potential for regional, national, and international networks. Some telemedicine experts recommend that the practice of telemedicine be handled differently than the practice of face-to-face medicine, as related to licensure (ie, a national or a regional geographic multistate licensure model).[20]

The liability of telemedical procedures has to be regulated according to national laws. The fact that teleconsultation in acute stroke is similar to face-to-face on-site consultation should facilitate these regulations.[21] Some physicians are concerned that they would be vulnerable to a malpractice lawsuit in the event that technical problems impede a consultation and result in an adverse outcome.[22] Given that telemedicine practice is not new, the ethical and malpractice aspects have largely been confronted and resolved.[23,24]

THE ECONOMIC ISSUES

Telemedicine networks, whether urban or rural, require a substantial capital investment in equipment and technical support. Components of the total cost of development and maintenance of a telestroke network include the telemedicine equipment, information technology support, the necessary clinical and administrative personnel, personnel training and credentialing, and allowances for on-call coverage.[25] Most telemedicine programs are financially dependent on public sector financing in the form of grants and telecommunications subsidies, which are nearly always restricted to rural counties. As a consequence, many telemedicine programs tend to be associated with academic medical systems in states and provinces with large rural areas and physician specialist shortages. These issues are even more complex when considering the economics of telestroke networks.[26]

Obtaining direct revenue from insurance payers for telestroke consultations is difficult. Medicare will only reimburse for telemedicine that includes consultations (Table 4) if the patient is linked with the hub vascular neurologist by live 2-way video communication and in instances when the spoke is located in an eligible geographic area. Medicare defines such eligible regions as rural health professional shortage areas and counties not

FIGURE 2. A hub hospital stroke neurologist and research coordinator are conducting a 2-way audiovisual telestroke consultation with the spoke hospital.

TABLE 4. **Medicare Reimbursement for Telemedicine Consultation**[a,b]

CPT code	Consultation duration (min)	Reimbursement amount (US $)
99241	15	45.92
99242	30	85.33
99243	40	117.08
99244	60	171.59
99245	80	211.74

[a] CPT = *Current Procedural Terminology*.
[b] For further information, see the telemedicine overview at Centers for Medicare & Medicaid Services (http://www.cms.hhs.gov/Telemedicine).

classified as a metropolitan statistical area. Although these restrictive circumstances exist in most states,[27] New York's state-based telestroke program has been bolstered by approval of Medicaid reimbursement for both ends of the consultation.[3] Confirmatory trials of telestroke efficacy coupled with cost-effectiveness analyses will provide health care policy makers with the data necessary to proceed with national telestroke reimbursement plans.

Historically, third-party payers have been slow to recognize teleconsultation activities for reimbursement; however, survey data indicate that the United States is progressing toward expanded private reimbursement for telemedicine services.[27,28] California, Louisiana, Kentucky, Texas, and Oklahoma have introduced legislation regarding mandatory private payer reimbursement for telemedicine.[28] Private reimbursement for telemedicine consultations was found to be generally comparable to that of traditional face-to-face consultations. Although surveys have recognized that small improvements in private reimbursement have occurred, this favorable change alone is insufficient to foster the creation of broader telemedicine networks.

No detailed, high-quality analyses of the cost-effectiveness of telemedicine for stroke have been performed, which has been a barrier to making a case for a uniform system for reimbursement for stroke teleconsultation.[26] Systematic reviews of cost-benefit studies of telemedicine in general in 2001-2002 reported that most did not meet acceptable quality criteria, most were restricted to simple cost comparisons, and no study used cost utility analysis or included sensitivity analyses.[29,30]

Several investigators have conducted financial analyses of the implementation of rural and urban telemedicine programs. Only those analyses conducted from the societal perspective have demonstrated profitable returns on investments.[31-33] In Denmark, the budgetary impact and cost-effectiveness of the national use of thrombolysis for stroke administered via telemedicine was estimated. The results demonstrated that thrombolysis by telestroke network was dominant to conservative management.[34] Studies conducted from the societal perspective, compared with those conducted from an institutional perspective, have a tendency to overestimate the total revenue. For example, when telestroke consultations prevent unnecessary air or ground transfers, the savings accrued do not directly benefit the health care institution that is investing the capital. Therefore, from the sponsoring institution's perspective, there is a perception that telemedicine is not a financially profitable endeavor. In the absence of ongoing government grant support, any telestroke-sponsoring institution must devise a business model that produces a self-sustaining profitable or break-even program.

REVIEW OF THE DEVELOPMENT OF A STATE TELESTROKE NETWORK

The Stroke Telemedicine for Arizona Rural Residents (STARR) network currently consists of a 1-hub, 2-spoke telestroke system. The road to the creation and implementation of this network was arduous. In preparation, 2 Mayo Clinic physicians (B.M.D., B.J.B.) visited previously established telestroke networks and reviewed the available telestroke technologies and equipment in 2005. In addition, a statewide needs assessment was administered to all remotely located hospitals with emergency departments in Arizona. This survey illustrated the need for increased access to stroke expertise in Arizona's rural communities, assessed each institution's current stroke resources, and demonstrated that most institutions were willing to and capable of participating in a telestroke initiative.[19] In 2006, a collaboration was initiated between Mayo Clinic and the University of California, San Diego, Stroke Team Remote Evaluation Using a Digital Observation Camera (STRokE DOC) trial (clinicaltrials.gov identifier: NCT00283868).

The foundation was laid for a randomized controlled trial to test the feasibility of a telestroke consultation performed via BF Technologies' STRokE DOC camera system vs telephone consultation in Arizona. This study, STRokE DOC Arizona—The Initial Mayo Clinic Experience (TIME) (clinicaltrials.gov identifier: NCT00623350),[16] was arranged to be a validation study of the University of California, San Diego, STRokE DOC research trial. The STARR group directors applied for an Arizona Department of Health Services (ADHS) research grant in 2006 to support 1 year of STRokE DOC Arizona TIME research. In 2007 the group applied for additional grant funds to support expansion of the STARR network for 5 years. The STARR team developed relationships with various emergency physicians and remote hospital personnel to begin forming the necessary telestroke teams at all involved sites. Yuma and Kingman Regional Medical Centers were selected as the spoke sites for the STRokE DOC Arizona

TIME trial and the overall STARR network. To initiate the spoke sites and complete necessary training, the STARR team conducted on-site visits and videoconferences. The ADHS grant made it possible to implement the telestroke system without imposing any start-up costs on the rural hospitals. As the project progressed, a series of part-time project managers were hired, and eventually a full-time project manager was brought onto the team. The STRokE DOC Arizona TIME trial commenced in December 2007. During the first year of operation, the STARR network used the BF Technologies camera system to perform telestroke consultations at the 2 spoke sites (Figure 3). The Digital Imaging and Communication in Medicine System was used for neuroimaging transmission. Four Mayo Clinic board-certified vascular neurologists shared the telestroke on-call duties (24 hours per day 7 days per week). A dedicated toll-free telestroke hotline and group paging system was established for the spoke centers to alert the on-call stroke neurologist. Although teleconsultations were generally easy to perform, occasional minor and major technological difficulties were noted.

From December 1, 2007, to May 31, 2008, the Mayo Clinic Hospital hub received approximately 16 hotline activations per month (2 per spoke center per week). Half of the calls did not meet stroke alert criteria on the basis of preliminary telephone screening. On average, 30% of all patients with stroke who received a full consultation were determined to be eligible for thrombolysis. Accordingly, thrombolysis administration for eligible patients with stroke increased 10- to 20-fold from the participating spoke hospitals' historic baseline in the first 6 months of the program (from approximately 0.5 to 1.0 per hospital per year to approximately 10 per hospital per year).

The STARR network experience has shown that a successful network is the product of hard-working, dedicated professionals at both the hub and spoke. Regular communication between hub and spoke is essential for maintaining enthusiasm for the project, good clinical practice guidelines, and troubleshooting of various logistical and technical complications that may arise. A weekly or monthly newsletter with updates, congratulations, and feedback is a useful mechanism for sustaining this open communication. Using the data derived from the Arizona state needs assessment,[19] the STARR network planned to expand by adding 4 additional spoke sites (Figure 4). When selecting new spokes for the network, the team considered the following aspects: size of the spoke hospital, volume of patients with stroke, regional need for stroke services, and desire and willingness of the spoke personnel to participate. Several options arise when exploring expansion opportunities for an existing telestroke network. For instance, the team considered new equipment options, addition of new support personnel to the team, development of a new method of operation, addition of new metropolitan PSC hubs,[35] and recruitment of additional vascular neurologists. Dividing the progression of the network into stages allows for revising and improving the existing network.

FIGURE 3. The BF Technologies (San Diego, CA) Stroke Team Remote Evaluation Using a Digital Observation Camera used for the Stroke Telemedicine for Arizona Rural Residents study.

Although the ADHS grant funding will support network expansion for 5 years, transition to a self-sustaining business model is the expectation. This model would need to address internal (organizational, technical, and educational) and external (economic, legal, and market) business factors that are identified by other telestroke networks as being important.[36] The Arizona Telemedicine Program, a long-standing multidisciplinary medical and surgical statewide network, published its business model in 2005, which could serve as a starting point.[37]

RESEARCH ADVANCES IN STROKE TELEMEDICINE

Telephone guidance for acute stroke is not a novel approach to overcoming the shortage of stroke neurologists in

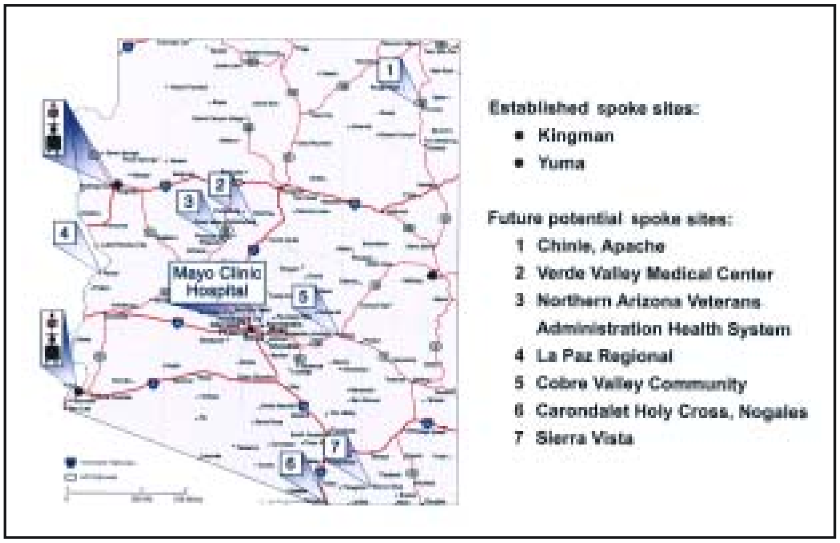

FIGURE 4. The Stroke Telemedicine for Arizona Rural Residents network map outlining hub and spoke (current and potential) hospitals.

both urban and rural environments. The telephone stroke consultation has a natural appeal in terms of its long history of use, universal availability, low cost, and simplicity. Frey et al[38] showed that a "drip and ship" (ie, intravenous thrombolysis initiated at remote hospital followed by transport to PSC) tPA treatment algorithm via telephone stroke consultation was as effective and time-efficient as standard face-to-face PSC evaluation of patients with stroke. Furthermore, Vaishnav et al[39] published a retrospective survey of rural patients who received thrombolysis by telephone-assisted stroke consultation. The authors concluded that this protocol was safe, practical, and effective with treatment times that did not differ significantly from published randomized controlled trials.

New stroke AV telemedicine consultation systems must be compared with standard, telephone-guided protocols. Randomized controlled trials that compare AV telemedicine with telephone stroke consultations include the University of California, San Diego, STRokE DOC trial (clinicaltrials.gov identifier: NCT00283868), Mayo Clinic STRokE DOC Arizona TIME (clinicaltrials.gov identifier: NCT00623350), and TRUST-tPA: Therapeutic Trial Evaluating Efficacy of Telemedicine (TELESTROKE) of Patients with Acute Stroke (clinicaltrials.gov identifier: NCT00279149). The University of California, San Diego, STRokE DOC study was the first of these 3 trials to be published and was made available online on August 3, 2008. Meyer et al[40] reported that correct decisions concerning suitability for thrombolysis were made more often in the telemedicine group than in the telephone group (98% vs 82%; odds ratio, 10.9; 95% confidence interval, 2.7-44.6; P=.0009). Stroke telemedicine consultations seem to result in more accurate decision making compared with telephone consultations. The completion of remaining trials and publication of the results will provide additional information about the comparison of telemedicine and telephone consultation in stroke care.

Through systematic review, 20 telestroke networks were identified (15 in North America and 5 in Europe) (Figure 5). Twelve of these networks have published their telestroke research experiences: Partners Telestroke Center,[41] Telemedic Project for Integrative Stroke Care,[3,42-48] Remote Evaluation of Acute Ischemic Stroke,[2,49-53] Telemedicine in Stroke in Swabia,[54] Maryland Brain Attack Center,[55] STARR,[16,19] University of Pittsburgh,[56] STRokE DOC,[10,40,57] Michigan Stroke Network,[58] Ontario Telehealth Network Telestroke Program,[4,59] University of Texas,[14] and Emergency Neurology Network-Stroke[60] (Table 5). Established networks with published data are relatively small in size and scope and receive manageable call frequencies. Few technical complications were reported. A high proportion of telestroke consultations resulted in thrombolysis. Quality outcome measures indicating a need for improvement included speed and efficiency of the consultation and care and rates of symptomatic intracranial hemorrhage in thrombolysis recipients.

THE FUTURE OF TELEMEDICINE IN THE NEUROSCIENCES

The future of telemedicine in the neurosciences encompasses clinical, research, and education applications. Most

United States

1 STARR, Mayo Clinic Arizona, Phoenix
2 STRokE DOC, University of California San Diego, San Diego
3 REACH, Medical College of Georgia, Augusta
4 Partners Telestroke Center, Massachusetts General Hospital, Boston
5 Maryland Brain Attack Center, University of Maryland, Baltimore
6 Michigan Stroke Network, St Joseph Mercy Hospital, Detroit
7 University of Texas Health Sciences Center, Houston
8 University of Pittsburgh Medical Center, Pittsburgh, PA
9 Utah Telehealth Network, University of Utah, Salt Lake City
10 University of California Los Angeles, Los Angeles
11 Renown Institute for Neuroscience, Reno, NV
12 Colorado Neurological Stroke Center, Englewood

Canada

13 Ontario Telehealth Network Telestroke Program, Toronto, ON
14 Alberta Provincial Stroke Strategy Telestroke Initiative, Calgary and Edmonton, AB
15 British Columbia Provincial Telestroke Initiative, Vancouver, BC

Europe

16 TEMPiS, Bavaria, Germany
17 TESS, Swabia, Germany
18 RUN-Stroke, France
19 STENO Stroke Network, University of Erlangen, Erlangen, Germany
20 Helsinki University Central Hospital, University of Helsinki, Helsinki, Finland

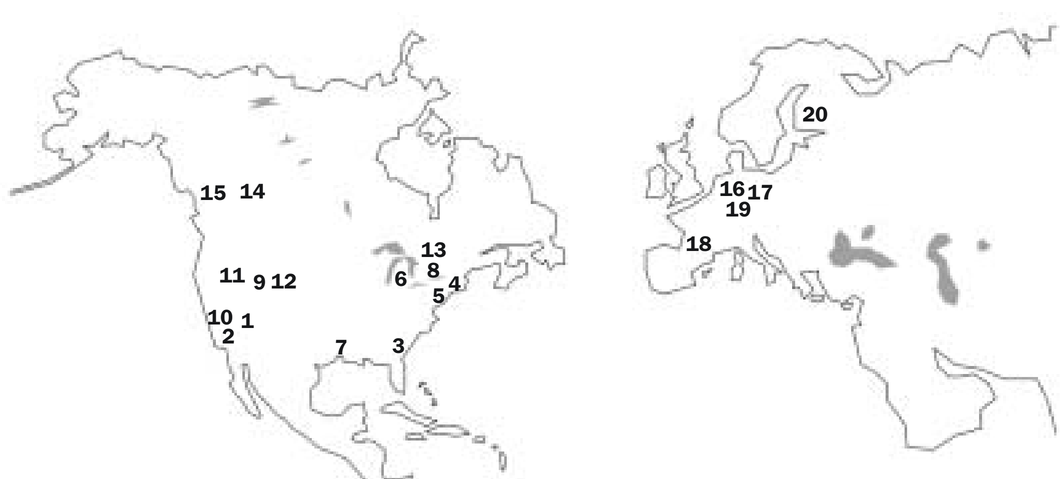

FIGURE 5. Map of current North American and European telestroke networks. REACH = Remote Evaluation of Acute Ischemic Stroke; RUN-Stroke = Emergency Neurology Network-Stroke; STARR = Stroke Telemedicine for Arizona Rural Residents; STENO = Stroke Network of University of Erlangen; STRokE DOC = Stroke Team Remote Evaluation Using a Digital Observation Camera; TEMPiS = Telemedic Project for Integrative Stroke Care; TESS = Telemedicine in Stroke in Swabia.

countries experience a perennial shortage of clinical neuroscience specialists outside metropolitan and urban sectors. Organizing regionally specific stroke systems of care that include telemedicine is an accepted solution to the global stroke epidemic.[61] In addition to consideration of telestroke applications, the use of telemedicine for all clinical neuroscience disciplines is being pursued on an international scale.[62,63] Telemedicine is useful not only in the emergency department but also in the prehospital ambulance setting,[7] the intensive care unit, rehabilitation, and outpatient stroke prevention clinics.

A developed telestroke network may offer an excellent forum for collaborative clinical research between university stroke centers and smaller remote hospitals.[26] Hub hospitals engaged in acute stroke trials could use telemedicine to screen, obtain consent from, enroll, randomize,

TABLE 5. **Telestroke Research Experiences of 12 Networks**

	PTC[41]	TEMPiS[3,42-48]	REACH[2,49-53]	TESS[54]	Maryland Brain Attack Center[55]	STARR[16,19]	Univ of Pittsburgh Medical Center[56]	STRokE DOC[10,40,57]	Michigan Stroke Network[58]	Ontario Telehealth Network[4,59]	Univ of Texas HSC[14]	RUN-Stroke[60]
Location	Boston, MA	Bavaria, Germany	Augusta, GA	Swabia, Germany	Baltimore, MD	Phoenix, AZ	Pittsburgh, PA	San Diego, CA	Detroit, MI	Toronto, ON	Houston, TX	France
No. of hubs/spoke hospitals	NA/1	2/12	1/8	1/7	1/1	1/2	1/9	1/4	1/22	2/2	1/2	1/11
No. of teleconsultants	NA	5	5	4	5	4	NA	3	NA	6	3	NA
Study duration (mo)	27	20	26	18	36	6	15	44	9	34	13	NA
Study consultations performed	24	396	194	153	23	33	33	223	90	88	NA	1000
Rate of calls to hub per 24 h	0.03	NA	0.25	0.28	0.05	0.18	0.07	0.17	0.33	0.09	NA	NA
ED arrival to consultation (min)	70	NA	44	69	NA	85	NA	70	NA	NA	NA	NA
Mean consultation duration (min)	NA	15	NA	15	NA	55	NA	28	NA	NA	NA	NA
ED arrival to tPA (min)	106	78	105	NA	NA	124	70	110	NA	NA	85	NA
Stroke onset to tPA (min)	124	NA	111	NA	NA	158	NA	151	NA	NA	NA	NA
No. of tPA administrations	6	86	30	2	5	10	NA	56	16	27	14	NA
Evaluated patients receiving tPA (%)	40	22	16	1	24	30	NA	25	18	30	NA	NA
tPA protocol violations (%)	0	NA	NA	0	NA	40	6	14	NA	NA	NA	NA
SICH/ASICH (%)	16.7/16.7	8.5/NA	0/0	50/0	NA/NA	10/0	NA/NA	7/NA	NA/NA	NA/NA	NA/NA	0/0
Technical complications (%)	7	NA	3	0	9	67	NA	19	NA	NA	2	NA
Mimics (% of consultations)	33	12	9	26	NA	NA	NA	8	NA	NA	NA	NA
Consultations resulting in transfer (%)	27	5	72	NA	24	45	NA	66	36	NA	NA	NA

[a] ASICH = asymptomatic intracranial hemorrhage; ED = emergency department; HSC = Health Sciences Center; NA = not available; PTC = Partners Telestroke Center; REACH = Remote Evaluation of Acute Ischemic Stroke; RUN-Stroke = Emergency Neurology Network-Stroke; SICH = symptomatic intracranial hemorrhage; STARR = Stroke Telemedicine for Arizona Rural Residents; STRokE DOC = Stroke Team Remote Evaluation Using a Digital Observation Camera; TEMPiS = Telemedic Project for Integrative Stroke Care; TESS = Telemedicine in Stroke in Swabia; tPA = tissue plasminogen activator; Univ = university.

treat, and follow up patients. Spoke subinvestigators could partner with experienced hub hospital investigators to form a research team. On-site pharmacies would be needed at each spoke. For more complex experimental intra-arterial therapies, telemedicine could be used to identify eligible patients, obtain their consent, and randomize them before transport from spoke to hub hospital for definitive treatment.[11] Although several authors have suggested that telemedical assessment could realistically be used to select patients for clinical trials, its actual use for this purpose has not been reported.[7,11,21,26,64,65] Contributing factors could include the research inexperience of some spoke hospitals that do not apply to an IRB, long interhospital transport times, spoke reimbursement issues, and hub IRB discomfort with the oversight of off-site research.

The telemedicine system can also serve as an educational tool. Spoke initiation training, continuing medical education lectures, stroke education, and quality assessment and improvement meetings can be delivered via the network. For example, the network could serve as a platform from which to teach spoke centers about novel stroke therapies and their implementation.[11] Telementoring facilitates the training and supervision of physicians in acute stroke practice at both the hub and spoke hospitals.

CONCLUSION

Since Levine and Gorman proposed the application of telemedicine for stroke in 1999, the field has been advancing at an international level. The architecture and design of rural and urban telestroke networks are now better defined. The technology has been adapted to suit the needs of an emergency, time-sensitive, acute stroke encounter. Well-designed studies have shown that this consultative modality is valid, accurate, and reliable. Numerous telestroke networks exist worldwide, and most of these networks have published their implementation experiences and early outcome results. Importantly, sophisticated 2-way AV telestroke consultations are being rigorously compared with simple pragmatic telephone consultations in prospective randomized controlled trials. Successfully delivered promises of telestroke include remote instant expert stroke diagnoses, delivery of short-term therapies, and secondary prevention advice. Promises of telestroke applications that have been slower to materialize include widespread national and international telestroke networks that offer standardized evidence-based care, telestroke research networks for testing new stroke therapies, standardized measurements of telestroke quality of care, and acceptable guidelines for telestroke practice. The long-term sustainability and growth of telestroke practice remain threatened by unresolved legal, economic, and market factors. Telestroke practitioners and investigators should focus attention on analyzing and solving the business issues of the practice to allow further advances in the telestroke field and longevity of telestroke practice.

We acknowledge Brett C. Meyer, MD, Janet D. Werner, RN, and their colleagues at University of California, San Diego, and Elaine J. Skalabrin, MD, and her colleagues at University of Utah for teaching us about telestroke research and practice; Kingman and Yuma Regional Medical Centers for being the first Arizona spoke sites; Laura C. Pappagallo, RN, Kelley J. Dunkowski, MBA, and Paola G. Scarberry for being the first Arizona telestroke project managers; Nicole L. Olmstead and Cristina T. Lipinski, RN, for serving as telestroke research monitors; Carol B. Garrison for assisting us with credentialing and privileging; Michael E. Brown, JD, for legal input; Bonnie L. Schimek for graphic designs and medical imaging; David A. Rose and Chrisann Tortora for photography; and Nicole D. Mullins and Pat H. Miller, RN, for stroke center administration and nursing.

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